COMPARISON OF BIODIESEL PROPERTIES PRODUCED FROM MORINGA OLEIFERA OIL AND PALM OIL.

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ABSTRACT

Continuous exploration of fossil fuel had diminished the reserve and turned the valuable non-renewable fuel into scarce. Even worse, the effect of fossil fuel combustion and volatile price had urged the scientific community to find a better substitute to a declining fossil fuel. Years of efforts had shed some light into a better solution of producing fuel from biomass source such as vegetable oils. The *Moringa oleifera* oil was extracted using different solvent in soxhelt extractor. The biodiesel was produced from crude palm oil and extracted *Moringa oleifera* oil through transesterification process using methanol and potassium hydroxide as catalyst. As a conclusion, n-Hexane was the best solvent which yielded the highest oil with an average percentage of 34.3%. The biodiesel properties of *Moringa oleifera* oil and palm oil such as cetane number were 66.7 and 59.5, kinematic viscosity were 4.8mm^2/s and 5.03 mm^2/s, cloud point were 18^oC and 16^oC, pour point 12^oC and 7^oC, flash point 165 and 160, and density 875kg/m^3 and 890kg/m^3. Biodiesel produced from *Moringa oleifera* had a potential to become a better feedstock as it possess a better properties which compare to biodiesel produce from palm oil.

ABSTRAK

Penerokaan petroleum yang berterusan menyebabkan simpanan bahan bakar tersebut berkurangan. Kesan buruk pembakaran dan harga bahan bakar tersebut yang tidak stabil telah memaksa para saintis untuk mencari penyelesaian terbaik kepada masalah ini. Selepas bertahun penyelidikan, biodiesel yang dihasilkan dari sumber yang boleh diperbaharui ialah jawapan terbaik terhadap kemelut tenaga yang semakin meruncing. Minyak *Moringa oleifera* diekstrak menggunakan tiga pelarut berbeza didalam Pemerah Soxhelt. Biodiesel dihasilkan melalui proses transesterifikasi dengan kehadiran metanol dan mangan. Kesimpulanya, n-Heksana ialah pelarut terbaik kerana menghasilkan minyak yang terbanyak dengan purata 34.3%. Ciri-ciri fizikal biodiesel dari minyak *Moringa oleifera* dan minyak kelapa sawit seperti nombor setana adalah 66.7 dan 59.5, kelikatan kinematic adalah 4.8mm^2/s dan 5.03 mm^2/s, *cloud point* adalah 18^oC dan 16^oC, *pour point* adalah 12^oC dan 7^oC, flash point adalah 165^oC and 160^oC, dan ketumpatan 875kg/m^3 dan 890kg/m^3. Biodiesel yang dihasilkan dari *Moringa oleifera* mempunyai potensi untuk menjadi bahan mentah yang lebih baik kerana ia mempunyai ciri-ciri yang lebih baik berbanding dengan biodiesel yang dihasilkan daripada minyak sawit.

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
CP	Cloud point
CFPP	Cold filter plugging point
CPO	Crude palm oil
CMOO	Crude *Moringa oleifera* oil
FA	Fatty Acid
FAME	Fatty acid methyl ester
FP	Flash Point
GHG	Green House Gas
MOME	*Moringa oleifera* methyl ester
POME	Palm oil methyl ester
PP	Pour point
rpm	round per minute

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1 INTRODUCTION

1.1 Background of study

The world's fossil fuel reserve is diminishing and become scarce (Demirbas, 2007) due to decades of continuous finding pockets of this valuable so called black gold or fossil fuel, pumping them dry and moving on to new finding. As this trend continues and couple with the imbalance of fossil fuel consumption and production, shrink the amount of non-renewable fuel reserve from undiscovered oil well, make it even harder to discover and more expensive to produce (Harper *et al*, 2009). Furthermore, when petroleum fuels are burned, lots of harmful gases such as carbon dioxide will be released into the atmosphere and pose adverse effect to environment and human health. This is because carbon dioxide is a gas that absorb heat. Sulfur dioxide also a side product which will be released from the fossil fuel combustion. When sulfur dioxide react with water in the atmosphere, a sulfuric acid will be formed. This sulfuric acid will lead to acid rain which will alter the natural pH value of soil and give a bad effect to the agriculture sector (Demshemino, 2013). If there is no concrete prevention efforts taken to alleviate above-mentioned threat, it is predicted that greenhouse gas (GHG) emissions from fossil fuels will increase by 39% in 2030 (Mofijur *et al*, 2014a)

This current scenario coupled with negative effect from the intense use of fossil fuel had triggered scientific community to carry out a scientific researches to seek the best alternative fuel source (Lim and Teong, 2010; Jayed *et al*., 2011 and Atabani *et al*., 2012) to cope with the problem and meet the ever increase fuel demand by reducing the dependence on petroleum derived fuel and shifting to renewable biofuel that are available, technically feasible, economically viable, and environmentally acceptable (Liaquat *et al*, 2010) which possess a characteristics of lower emissions of carbon monoxide, particulate matter, and total hydrocarbons which would help to reduce the air pollution. After years of scientific research, the effort has paid off as the scientific community successfully developed a new kind of fuel. It is accepted in many countries as an extender or substitute for fossil based diesel. Besides possesses physiochemical properties very similar to those of petroleum-based diesel (Ávila and Sodré, 2012, Amani et al., 2013 and Thomas et al., 2013), this new kind of biofuel having the advantages of being biodegradable, renewable, possesses inherent lubricity, relatively high flash point, 10 times less poisonous compared to the ordinary diesel oil, the waste product is

not black, less sulphur and other aromatic contents, hence the combustion emission produced is safe for environment and perform less accumulation of carbon dioxide gas in atmosphere thus lessen furthermore global heating effect, and it can be used easily because it can be mixed at any proportion with diesel oil, hence enabling us to apply it immediately for diesel engines that are available without much modification (Trakarnpruk and Chuayplod, 2012 ; Abdullah *et al*., 2009; Christian *et al*., 2009; Sérgio and Graciela, 2006; Lìlian *et al*.,2008; Haseeb *et al*., 2011; Cumali *et al*., 2011).

Biofuels is really an umbrella term and it can mean almost anything, from hydroelectric power, which is generated from waves to wind, solar and other forms of generating energy. However, for the most part the term biofuels is used to refer to that of alternative substitutes for petrol, diesel or aircraft fuel. Biofuel can be explained as transportation liquid or gaseous fuels that predominantly produced from biomass (Demirbas, 2006). Biofuels are a viable alternative to fossil fuels. Many varieties exist and they vary significantly. Some examples are that of biodiesel, which entails growing crops that contain high amounts of natural oil then through a process of hydrogenation or refining a more compatible biodiesel, substitute is created. This creates a biodiesel, which can be mixed with mineral diesel or use on its own then used in any diesel-powered automobile.

Biodiesel is an animal fat or vegetable oil based diesel fuel that burns without the emission of much soot, carbon IV oxide and particulate matter. (Oliveira and Da Silva, 2013). Biodiesel can be produced from numerous primary feed stocks of either vegetable oils or animal fats such as canola (rapeseed) oil, tobacco oil, jatropha oil, cottonseed oil, sunflower oil, soybean oil, palm oil, peanut oil, rubber seed oil, as well as variety of less common oil. Above mentioned primary feed stocks are allowed to react chemically with an alcohol and the most commonly use alcohol is methyl alcohol with the present of catalyst which usually a strong base such as sodium or potassium hydroxide. This chemical reaction will yield a new chemical compound called methyl ester or popularly known by people as biodiesel (Gerpen, 2005).

1.2 Botanical Description of Moringa oleifera

Although there is variety of choices of feed stocks for the production biodiesel but only two will be focused in this work which are *Moringa oleifera* seed oil and palm oil. *Moringa oleifera* seeds can be obtained from a tree with a cluster of small oval leaves and delicately perfumed cream-coloured flowers called *Moringa oleifera*. It is also called Miracle tree or Tree of life

(Sue Nelson and Marlene Rau, 2011). *Moringa oleifera* is one of the species in monogeneric family of shrubs and tree, moringaceae (Dalziel, 1995). It is native to the foothills of Himalayas of northern India (Patty Donovan, 2007) and nowadays it is cultivated well beyond it native range throughout South Asia, Arabian Peninsula, tropical Africa, central America, the Caribbean and tropical South America (Roloff et al, 2009).

Figure 1: a) Ripe *Moringa oleifera* pods b) Inside the pod c) *Moringa oleifera* seeds with shell d) *Moringa oleifera* kernels

A highly valued plants and fast-growing *Moringa oleifera* able to tolerate with a wide range of environmental conditions. It can resist a light frost and best grows between 25 to 35^{o}C but able to tolerate up to 48^{o}C in the shade. The drought-tolerant tree also able to adapt in poor soil condition, receive wide range of rainfall amounts of 25cm to 150cm, adaptable best below 600m altitudes and soil pH of 5.0–9.0 (Palada and Changl, 2003). Oil extracted from *Moringa oleifera* can be used as raw material to produce biodiesel just like palm oil. Bark, roots, seeds, flowers and leaves of this tree can be used for various purposes such as treat various ailments, combating malnutrition, culinary, production of cosmetic, soap and many more but besides that it also can be used to produce biodiesel (Ramachandran et al, 1980).

Oil extracted from *Moringa oleifera* seeds concentrate between 35-45 % (w/w) of vegetable oil (Ricardo, 2012) known as "Behen" or "Ben" oil from its high concentration of behenic acid (Abiodun, 2012) possesses significant resistance to oxidative degradation (Stavros Lalas and John Tsaknis, 2002). Fatty acids composition in *Moringa oleifera* resembles olive oil and it is rich in palmetic, stearic, behmic, and oleic acids which is ideal for edible purpose (García-Fayos et al, 2010). Based on comparative analysis using smells and odours electronic detection device or eNose, oil extracted from *Moringa oleifera* also possesses a pleasant peanut-like odour and pale yellow in colour (Abdulkarim et al, 2005)..

1.3 Motivation

Unlike any other primary feed stocks, oil extracted from *Moringa oleifera* seeds have high cetane number which is more than 60 (Trakarnpruk and Chuayplod, 2012). The high cetane number in the oil will ensure a proper solid ignition. Furthermore, a high rating of cetane number would help to reduce a carbon release footprint, improved fuel efficiency and reduce tear and wear for both vehicle starter and batteries (Masina et al, 2012).

As compared to other feed stocks especially palm oil, oil derived *Moringa olei*fera seeds has a better oxidative stability. The price of the *Moringa oleifera* crude oils is comparable to soybean crude oil and palm oil. From economical view, *Moringa oleifera* can be planted with a less water, less nutrient and improper soil condition and this will lead to cheaper cost to cultivate (Masina et al, 2012).

Moreover, the production of biodiesel from *Moringa oleifera* will reduce the demand for the palm oil for biodiesel production thus reduce the price and pressure on food industry to meet the ever skyrocketing demand for palm oil especially during festive seasons. The plantation of these trees can potentially increase green coverage to sequester more CO_2 than other vegetable oil crops. *Moringa oleifera* can withstand drought, it is able to produce seeds in the first year and harvest up to four times in a year (Wahidul and Michele, 2009)

1.4 Problem statement

Nowadays, fatty acid methyl ester (FAME) or popularly known as biodiesel which is derived from various vegetable and animal fats has been hailed as the potential substitute to replace petroleum-based diesel and possible solution for the shortage of transportation fuel and to

reduce the greenhouse effects and pollution caused by conventional diesel. The substitution to tryglyceride-based biodiesel is due to similarity of energy content, viscosity, cetane number and phase changes of biodiesel to those of petroleum-derived diesel fuel (Yee and Lee, 2008). Moreover, the usage of biodiesel from renewable oil sources have the benefits of lower sulfur content, lower aromatic content, higher heat content, biodegradability, renewability, ready availability and liquid nature-portability (Demirbas, 2005).

On the other hand, the production of biodiesel from vegetable oils has triggered a new problem of shortage vegetable oil for human daily consumption as the most abundant vegetable oil in the region is the most common feedstock. For example in Malaysia, palm oil is the feedstock to produce biodiesel and in the same time it also being used to produce foods (Knothe et al, 2005). The increasing usage of palm oil for biodiesel production raised tension for palm oil producer to meet the ever-increase demand and has crop-up a new problem of food production, price and availability (Torrey, 2007). Therefore, the study to seek the best feedstock must be carried out in order to solve fore mentioned problem. Different usage of solvent in oil extraction process might affect the oil recovery or oil yield. Normally, n-Hexane is used in Solvent Extraction which yields about 38.40% but the use of ethanol might increase the oil yield (Sajid Latif and Farooq Anwar, 2008). Therefore, the use of different solvent in the oil extraction is vital in order to improve the oil yield.

1.5 Objectives

The following are the objectives of this research:

i. To produce an environmental friendly biodiesel from palm oil and extracted *Moringa oleifera* oil.

ii. To study the effect of different solvent in oil extraction process.

iii. To compare biodiesel properties produced from *Moringa oleifera* and palm oil.

1.6 Scope of this research

The following are the scope of this research:

i. The *Moringa oleifera* oil will be extracted through solvent extraction process using Soxhelt Extractor. Ethanol,methanol and n-hexane will be used as solvent. The purpose of using different solvents is to study the amount of yield from different solvent.

ii. Palm oil and extracted *Moringa oleifera* oil will be converted into biodiesel through transesterification process with the presence of methanol and potassium hydroxide as a catalyst.

iii. The produced biodiesel will be analysed and to measure properties such as cetane number, kinematic viscosity, cloud point, pour point, density, and flash point.

2 LITERATURE REVIEW

2.1 Overview

Biodiesel is an environmentally attractive alternative fuel to petrodiesel which can be defined as long-chain mono-alkyl esters of vegetable oils or animal fats and is produced through transesterification process with a monohydric alcohol usually methanol. The converted tryglycride is formed depends on the type of alcohol used. If methanol is used, the chemical reaction will yield methyl ester but if ethanol is used, ethyl ester will be produced (Abdulkareem1 *et al*, 2011).

The production of biodiesel from *Moringa oleifera* seeds consists of few methods. The ripe and dried-seeds are removed from long pods, and kernels are obtained from the seeds. Kernels are grounded using laboratory mortar and pestle (Arafat, 2013). The extraction of oil is carried out to proceed the process using different methods such as manual method (batch) which is seeds were defatted by using 95% ethanol in 5 % (w/v) suspension, mixing with a magnetic stirrer for 60 minutes. Supernatant was separated by centrifugation (3000 rpm, 45 min) and the settled powder was dried at room temperature for 24 hours (García-Fayos et al, 2010). Besides above method, a much well-known method is using Soxhelt extractor. 10g of grounded *Moringa oleifera* kernel is fed into thimbles of the electro thermal Soxhelt extraction chamber and 170ml hexane is pour into volumetric flask of Soxhelt extractor and the hexane is evaporated into three cycles for 30 minutes each cycle until hexane become colourless (Eman et al, 2012). According to Jessica et al. (2012), the amount of oil extracted from *Moringa oleifera* will be vary depending on the type of solvent used in the extraction process. For example, if ethanol is used, more oil will be extracted compared to methanol, petroleum and acetone.

Furthermore, the process is continued by transesterification of tryglycride, implementing standard procedure of 6:1 molar ratio of methanol to vegetable oil for one hour at 60^{o}C with 1 wt% Sodium methoxide ($NaOCH_3$) as catalyst. As the reaction ended, the product is let to cool at room temperature without agitation to separate the product into two phases. After removing the unwanted bottom products which consist of glycerol, excess methanol and catalyst, soaps formed during the reaction, some entrained methyl ester and partial glycerides by decantation, the excess methanol that settled above the methyl ester is also removed at 80^{o}C. Distilled water is used to wash out the remaining catalyst and residual water was removed by treatment with Na_2SO_4, followed by filtration (Umer et al, 2008).

The production of biodiesel from palm oil also undergoes the similar process of transesterification palm oil using methanol with the presence of sodium hydroxide as a catalyst. As the process ended, palm oil will be transformed into ester form and glycerol. The remaining ester is called biodiesel (Khalizani and Khalisanni, 2011; Ghanei *et al*., 2011; Sylvain *et al*., 2009; Mário and José, 2011). Products then were used to carry out properties determination process using various machines and standards.

2.2 Physico-chemical Properties of Crude Palm Oil (CPO) and Crude Moringa oleifera Oil (CMOO)

Table 2.1: Physico-chemical properties of crude palm oil (CPO) and crude *Moringa oleifera* oil.

Properties	Units	Standards	CPO	CMOO
Dynamic viscosity	mPa s	ASTM D445	36.30	38.90
Kinematic viscosity at 40 °C	mm^2/s	ASTM D445	40.40	43.33
Kinematic viscosity at 100 °C	mm^2/s	ASTM D445	8.43	8.91
Viscosity Index	–	N/A	192.1	193.1
Density	kg/m^3	ASTM D4052	898.4	897.5
Flash point	°C	ASTM D93	165	268.5
Pour point	°C	ASTM D97	9	11
Cloud point	°C	ASTM D2500	8	10
Calorific value	MJ/kg	ASTM D240	39.44	38.05
Acid value	mgKOH/g oil	ASTM D664	3.47	8.62

* Data from Mofiju *et al*, 2014a

2.3 Physico-chemical Properties of Biodiesel from Moringa oleifera Seed Oil

Table 2.2 shows properties of *Moringa oleifera* methyl esters with comparison to standards

Property	M. oleifera methyl esters*	ASTM D6751	EN 14214
Cetane number	67.07	47 min	51 min
Kinematic viscosity (mm2/s; 40^o C)	4.83	1.9–6.0	3.5–5.0
Cloud point (^{o}C)	18	-	-
Pour point (^{o}C)	17	-	-
Oxidative stability (h)	3.61	3 min	6 min
Lubricity (HFRR; μm)	135, 138.5	-	-

*Data from Umer Rashid, 2008

Table 2.3: Fatty acid profile of *Moringa oleifera* oil with typical profiles of palm, rapeseed (canola), soybean and sunflower oils shown for comparison purposes. *Moringa oleifera* oil contain high percentage of oleic acid which consider to be a healthy oil.

Fatty acid	Structure* (Carbon number)	Moringa oleifera[a]	Palm[b]	Rapeseed[b]	Soybean[b]	Sunflower
Palmitic acid	C16:0	6.5	44.1	3.6	11	6.4
Stearic acid	C18:0	6.0	4.4	1.5	4	4.5
Oleic acid	C18:1	72.2	39.0	61.6	23.4	24.9
Linoleic acid	C18:2	1.0	10.6	21.7	53.2	63.8
Alpha or gamma-linolenic acid	C18:3	–[c]	0.3	9.6	7.8	–[c]
Arachidic acid	C20:0	4.0	0.2	-	-	-
Eicosenic acid	C20:1	2.0	-	1.4	-	-
Behenic acid	C22:0	7.1	-	-	-	-
	Other	1	1.1% C14:0, traces of others	0.2% C22:1	Traces	Traces

[a] Data from Umer Rashid, 2008

[b] Data from Gunstone and Harwood, 2007. These values constitute averages of numerous samples.

[c] This may indicate traces (<1%) or absence of these fatty acids.

Data from Arjun *et al*, 2008

* Carbon number with ‘zero’ double bonds are saturated fatty acids, with ‘one’ double bonds are monosaturated and with ‘two’ and ‘three’ double bonds are polyunsaturated FA.

2.4 Physico-chemical Properties of Biodiesel from Palm Oil

Table 2.4: shows properties of Palm oil methyl esters with comparison to standards

Property	Palm Methyl Ester	ASTM D6751	EN 14214
Cetane number	65	47 min	51 min
Kinematic viscosity (mm2/s; 40^{o}C)	4.5	1.9–6.0	3.5–5.0
Cloud point (^{o}C)	16.0	-	-
Pour point (^{o}C)	16.0	-	-
Oxidative stability (h)	16[a]	3 min	6 min

Data from Jawad Nagi *et al*, 2008

[a] Data from Yung Chee Liang *et al*, 2013

2.5 Synthesis Routes

Nowadays, there are numerous synthesis routes in the production of biodiesel which using different alcohols and catalysts. Four of the biodiesel synthesis routes are direct use and blending of raw oils, micro-emulsions, thermal cracking (pyrolysis) and transesterification with process descriptions shown in Table 2.5, 2.6, 2.7 and 2.8 respectively. In this paper, transesterification was chosen to be the method to produce biodiesel because through this process, biodiesel will have a higher cetane number, lower emissions, higher combustion efficiency and renewable.

Table 2.5: Direct use and blending of raw oils process description

Process	• Direct use and blending
Definition	• Direct use as diesel fuel or blend with diesel fuel
Advantage	• Liquid nature-portability • Heat content (~80% of diesel fuel) • Readily available and renewability
Disadvantage	• Higher viscosity • Lower volatility • Reactivity of unsaturated hydrocarbon chains
Problems of using in engines	• Coking and trumpet formation • Carbon deposits • Oil ring sticking • Thickening and gelling of the lubricating oil
References	• Kaya *et al*(2009) • Issriyakul *et al* (2008) • Kansedo *et al* (2009) • Kumar Tiwari *et al* (2007) • Rao *et al* (2009).

Table 2.6: Micro-emulsions process description

Process	• Micro-emulsions
Definition	• A colloidal equilibrium dispersion of optically isotropic fluid microstructures with dimensions generally in the 1–150 nm range formed spontaneously from two immiscible liquids and one or more ionic or non-ionic amphiphiles
Advantage	• Better spray patterns during combustion • Lower fuel viscosities
Disadvantage	• Lower cetane number • Lower energy content

Problems of using in engines	• Irregular injector needle sticking • Incomplete combustion • Heavy carbon deposits • Increase lubrication oil viscosity
References	• Alonso *et al* (2008) • Sahoo and Das (2009) • Santos *et al* (2009 • Saraf and Thomas (2007) • Singh and Singh (2009) • Winayanuwattikun *et al*(2008)

Table 2.7: Thermal cracking (pyrolysis) process description

Process	• Thermal cracking (pyrolysis)
Definition	• The conversion of long-chain and saturated substance (biomass basis) to biodiesel by means of heat
Advantages	• Chemically similar to petroleum-derived gasoline and diesel fuel
Disadvantage	• Energy intensive and hence higher cost
Problems of using in engines	-
References	• Alonso *et al* (2008) • Santos *et al* (2009) • Saraf and Thomas (2007) • Singh and Singh (2009)

Table 2.8: Transesterification process description

Process	• Transesterification
Definition	• The reaction of a fat or oil with an alcohol in the presence of catalyst to form esters and glycerol
Advantages	• Renewability • Higher cetane number • Lower emissions • Higher combustion efficiency
Disadvantage	• Disposal of by-product (glycerol and waste water)
Problems of using in engines	–
References	• Schinas *et al* (2009)

2.6 Basic chemical reactions

Above figure depict the simplified form of chemical reaction which is presented in equation. Vegetable oils or animal fats are esters of saturated and unsaturated monocarboxylic acids with the trihydric alcohol glyceride. These esters are called triglycerides, which can react with alcohol in the presence of a catalyst, a process known as transesterification. R_1, R_2 and R_3 in

above figure are long-chain hydrocarbons, sometimes called fatty acid chains. Normally, there are five main types of chains in vegetable oils and animal oils: palmitic, stearic, oleic, linoleic, and linolenic. 1 mol of fatty ester is liberated at each step of the conversion process of triglyceride into diglyceride, monoglyceride, and finally to glycerol (Dennis *et al*, 2010).

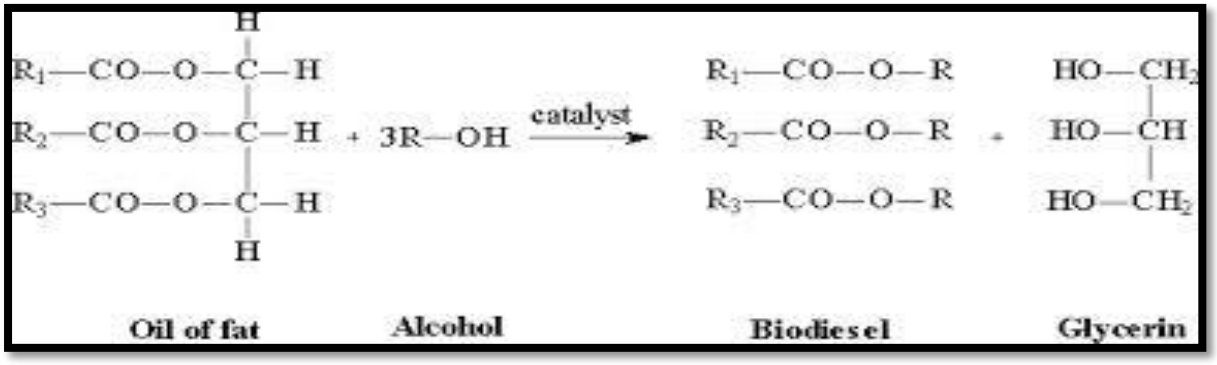

Figure 2.1: Basic chemical reaction

2.7 Catalyst

Normally, there are three type of catalysts being used in transesterification which are alkalis, acids, and enzymes. All three catalysts including their advantages, disadvantages and example of catalyst are shown in Tables 2.9, 2.10, 2.11, 2.12 and 2.13 respectively. In this research, potassium hydroxide was chosen as a catalyst to be used transesterification because it is cheaper and most commercially use in small and large scale biodiesel production compare to acid and enzyme catalyst (Umer and Anwar, 2008; Umer et al, 2008; Demirbas, 2008; Azcan and Danisman, 2007; Dias et al, 2008; Dizge et al, 2009; Dizge and Keskinler, 2008). The cost of transesterification process which use alkali catalyst especially potassium hydroxide is cheap because the process is carried out at low temperature of around 60^{o}C and pressure environment. Moreover, it require no intermediate step and high conversion rate.

Table 2.9: Alkali homogeneous catalyst

Alkali	
Type	• Homogeneous
Advantages	• High catalytic activity • Low cost • Favourable kinetics • modest operation conditions
Disadvantages	• Low FFA requirement • Anhydrous conditions • Saponification • Emulsion formation • More wastewater from purification • Disposable

Example	• NaOH • KOH
References	• Dizge *et al* (2009) • Qian *et al* (2008) • da Silva *et al* (2008) • Di Serio *et al* (2007) • Kawashima *et al* (2009)

Table 2.10: Alkali heterogeneous catalyst

Alkali	
Type	• Heterogeneous
Advantages	• Noncorrosive, • Environmentally benign • Recyclable • Fewer disposal problems • Easily separation • Higher selectivity • Longer catalyst lifetimes
Disadvantages	• Low FFA requirement • Anhydrous conditions • More wastewater from purification • High molar ratio of alcohol to oil requirement • High reaction temperature and pressure • Diffusion limitations • High cost
Example	• CaO • $CaTiO_3$ • $CaZrO_3$ • $CaO–CeO_2$ • $CaMnO_3$ • $Ca_2Fe_2O_5$ • KOH/Al_2O_3 • KOH/NaY • Al_2O_3/KI • ETS-10 zeolite • Alumina/silica supported K_2CO_3
References	• Liu *et al* (2008) • Kulkarni *et al* (2006) • Qian *et al* (2008) • Di Serio *et al* (2007) • Kawashima *et al* (2009)

Table 2.11: Acid homogeneous catalyst

Acid	
Type	• Homogeneous
Advantages	• Catalyse esterification and transesterification simultaneously • Avoid soap formation
Disadvantages	• Equipment corrosion • More waste from neutralization • Difficult to recycle • Higher reaction temperature • Long reaction times • Weak catalytic activity
Example	• Concentrated sulphuric acid
References	• Dizge *et al* (2009) • da Silva *et al* (2008) • Di Serio *et al* (2007)

Table 2.12: Acid heterogeneous catalyst

Acid	
Type	• Heterogeneous
Advantages	• Catalyze esterification and transesterification simultaneously, recyclable • Eco-friendly
Disadvantages	• Low acid site concentrations • Low microporosity • Diffusion limitations • High cost
Example	• ZnO/I_2 • ZrO_2/SO_4^{2-} • TiO_2/SO_4^{2-} • Carbon-based solid acid catalyst • Carbohydrate-derived catalyst • Vanadyl phosphate • Niobic acid • Sulphated zirconia • Amberlyst-15 • Nafion-NR50
References	• Lou *et al* (2008) • Dizge and Keskinler (2008) • Di Serio *et al* (2007) • Kawashima *et al* (2009)

Table 2.13: Enzyme catalyst

Enzyme	
Type	• Enzymes
Advantages	• Avoid soap formation • Non-polluting • Easier purification
Disadvantages	• Expensive • Denaturation
Example	• Candida antarctica fraction B lipase • Rhizomucor mieher lipase
References	• Haas (2005) • Lou *et al* (2008) • Kawashima *et al* (2009)

2.7 Alcohol

There are several types of alcohol that can be used in transesterification process such as methanol, ethanol, propanol, iso-propanol, butanol and amyl alcohol (Encinar *et al*., 2007; Wang *et al*. 2005; Mariod *et al*. 2006; Meneghetti *et al*. 2006; Yao and Hammond 2006; Dantas *et al*. 2007; Issariyakul *et al*. 2007; Kulkarni *et al*. 2007; Alamu *et al*. 2008; Domingos *et al*. 2008; Georgogianni *et al*. 2008; Lima *et al*. 2008; Rodrigues *et al*. 2008; Stavarache *et al*.2008). Among aforementioned alcohols, methanol is the most extensively used in the production of biodiesel (Chang and Liu, 2009). In this research, methanol also was used to react with both palm oil and *Moringa oleifera* oil to produce biodiesel because of its economical reason as well as its physical and chemical advantages. Moreover, methanol can react with vegetable oils or animal fats in a short period of time and potassium hydroxide is easily dissolved in it.